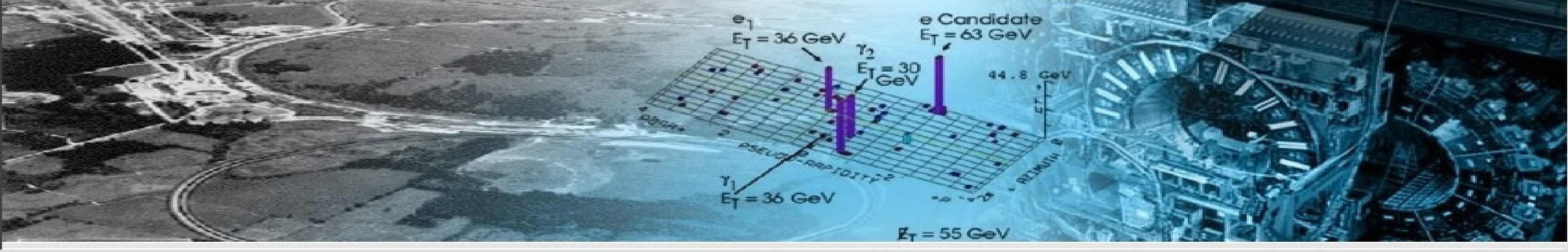

Search for Heavy, Neutral, Long-Lived Particles that Decay to Photons at CDF

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Outline

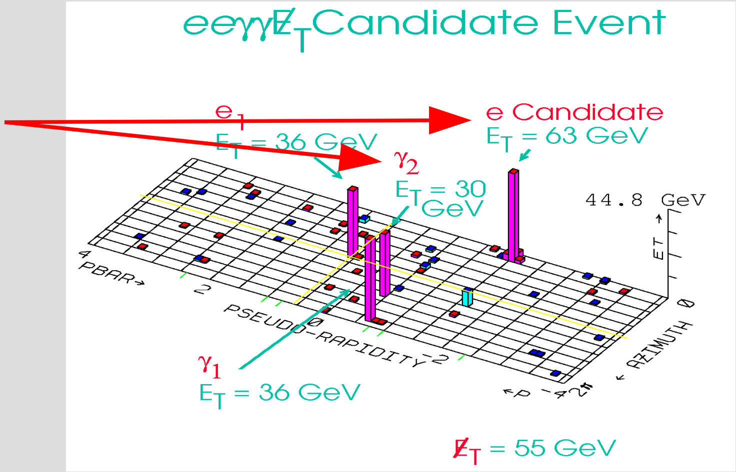
- Motivation and Theory
- The Tool: EMTiming
- Analysis
- Results
- Conclusion

Motivation

(1) First search for heavy, long-lived particles that decay to photons at a hadron collider

(2) "ee$\gamma\gamma$+$\not{E}_T$" candidate event at CDF in Run I

- One of the photons and the plug electron candidate had no time information. The SM prediction for this event was $1 \pm 1 \times 10^{-6}$ events
- Hypotheses: Some objects were not from the collision? Or from neutral, long-lived particles?

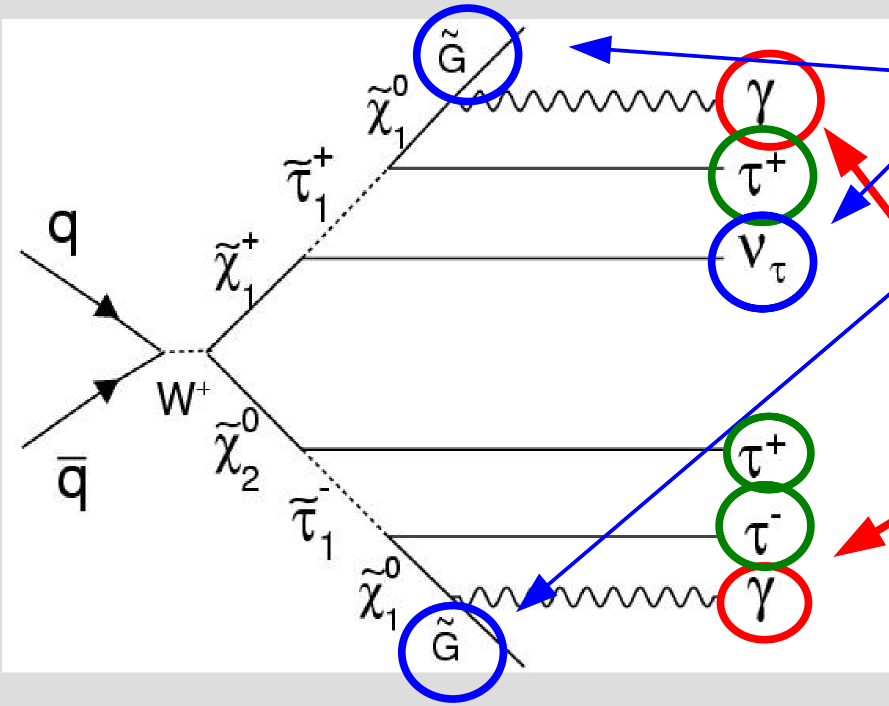


(3) Supersymmetric models – "Gauge Mediated Supersymmetry Breaking" (GMSB) – predict heavy, long-lived neutralinos that decay to photons ($\rightarrow$ next slides)

(4) Interesting cosmological implications for this parameter space

GMSB Phenomenology

- Lightest neutralino $\tilde{\chi}_1^0$ is NLSP and decays as $\tilde{\chi}_1^0 \rightarrow \tilde{G}\gamma$
- For much of the GMSB parameter space the $\tilde{\chi}_1^0$ decay time can be ~ns
- At the Tevatron neutralinos are pair-produced from $\tilde{\chi}_1^{\pm}\tilde{\chi}_1^{\pm}$ or $\tilde{\chi}_1^{\pm}\tilde{\chi}_2^0$



Leave the detector

Can be detected

Signature:

$\Rightarrow \not{E}_T$

Jets

$\Rightarrow \gamma\gamma$ or γ

if both or only 1 $\tilde{\chi}_1^0$ decay in the detector due to large decay lengths

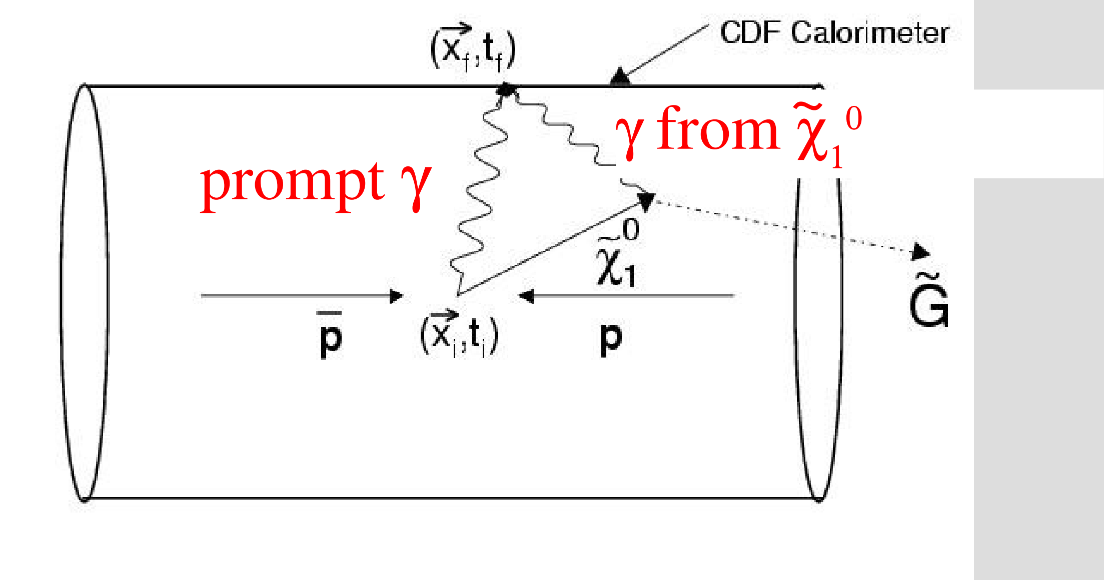
- Use this model to estimate our sensitivity

Delayed Photons

D. Toback and P. Wagner, Phys Rev D70, 114032 (2004)

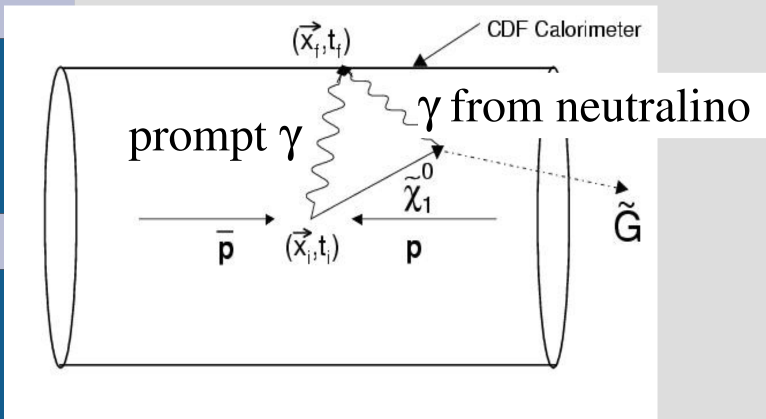
Photons from long-lived neutralinos can arrive at the calorimeter delayed compared to photons from the collision! $\Rightarrow$

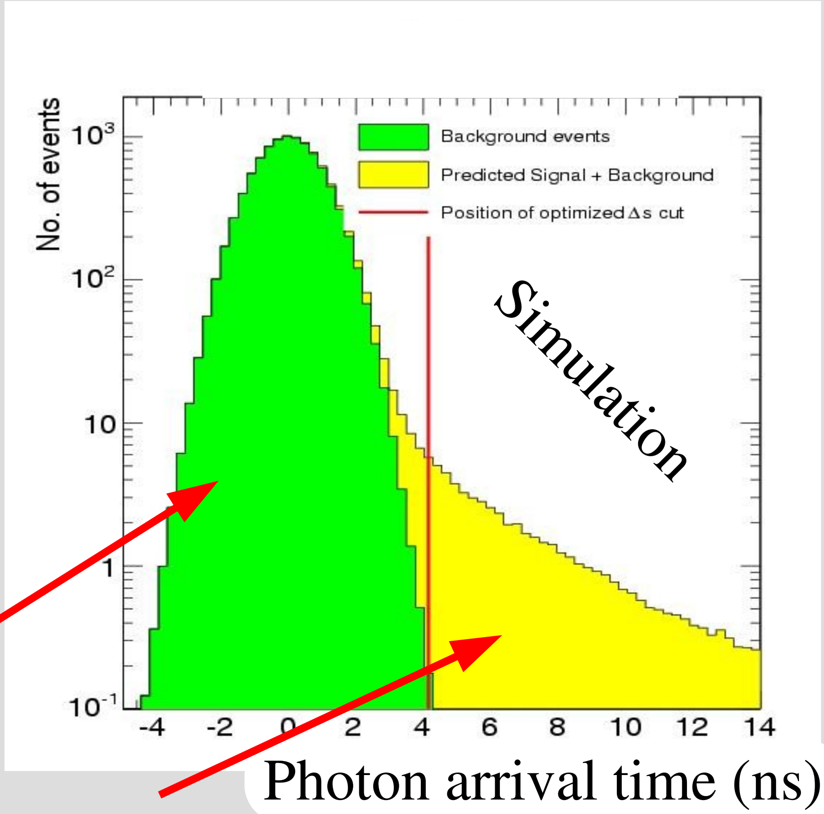
The idea: Look at the difference between the time of arrival of the photon and the time a prompt photon would need to reach the same position:



Search for $\gamma + \not{E}_T +$ jets events to be sensitive to longer $\tilde{\chi}_1^0$ lifetimes that are interesting for cosmology

Discriminating Search Variable





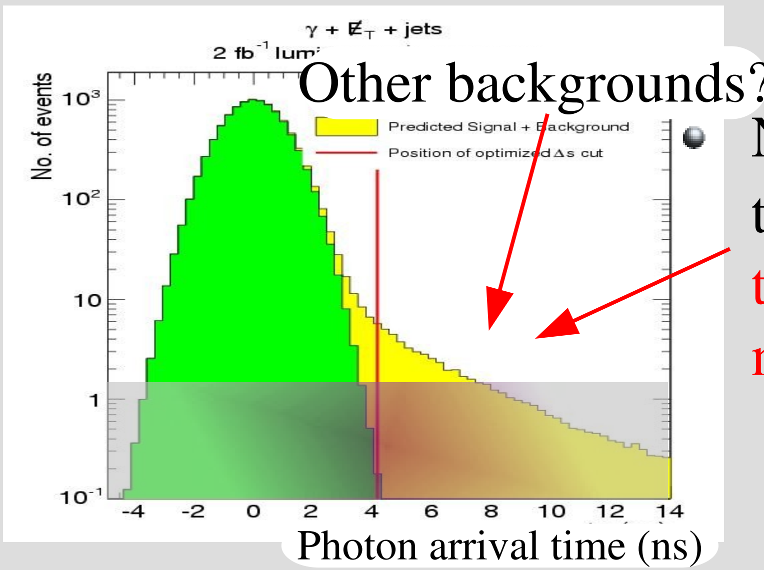
- Separate SM Background from GMSB Signal using
  (1) an arrival time measurement of the photon at the calorimeter
  (“EMTiming system” → next slides)
  (2) A time-sensitive vertexing
- Advantage: Low SM background at non-prompt arrival times

So how are we going to do it?

- We want to look for (delayed γ)+$\not\!\!E_T$+ jets events $\rightarrow$ need timing system
- We make a loose event selection such that we are sensitive to any model with a similar final state, then optimize our event selection requirements using a GMSB model for several $\tilde{\chi}_1^0$ masses and lifetimes

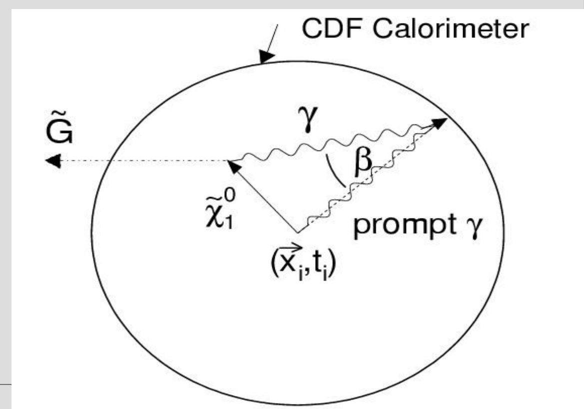
Then: Open the blinded signal region and discover SUSY... well...

Difficulties:



- Non-collision backgrounds at those arrival times $\rightarrow$ estimate their contribution directly from non-collision data

- Use modified photon identification criteria as photons from long-lived particles can arrive at unusual incident angles at the calorimeter



New: EMTiming at CDF

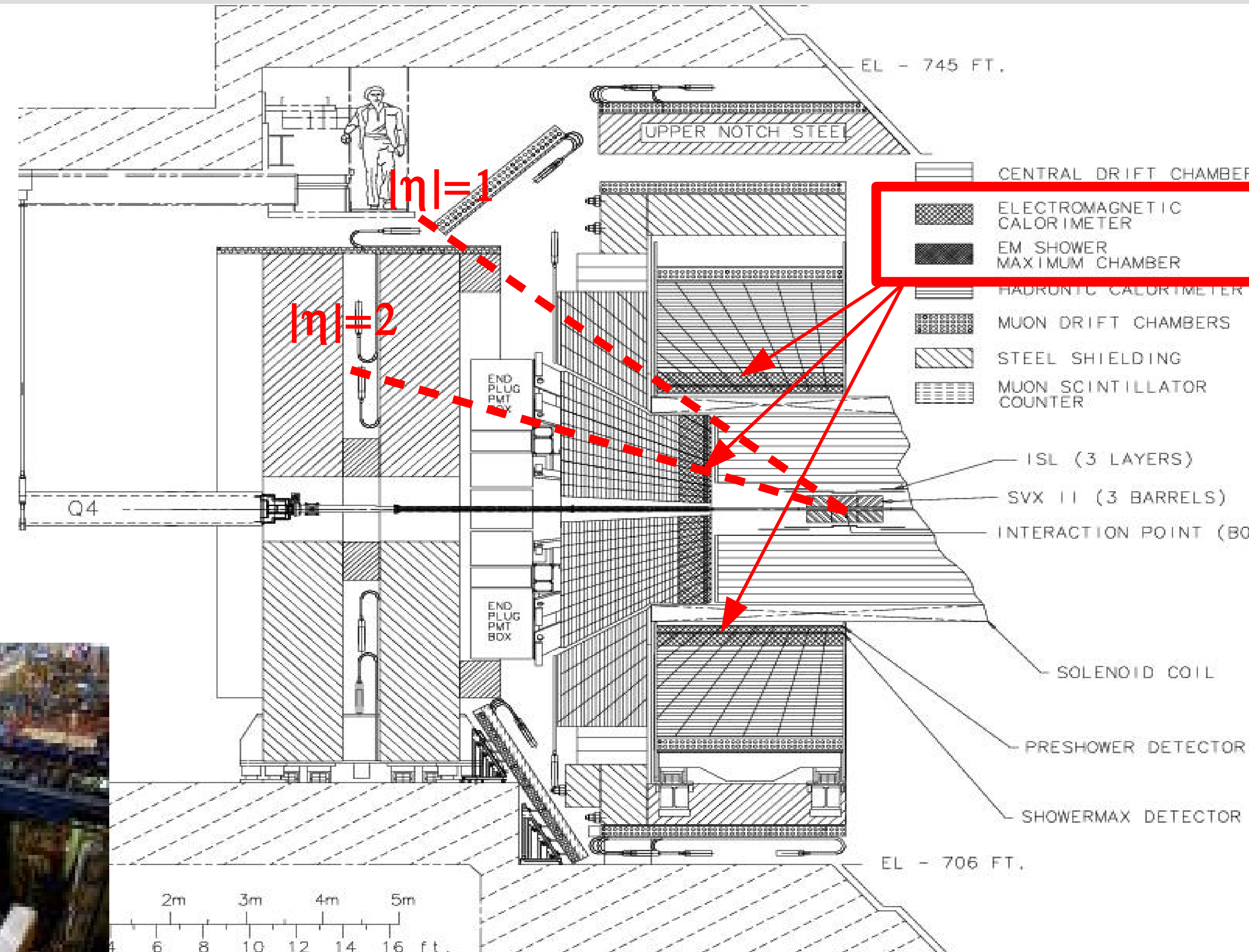
CDF II Detector

Tracker:

- SVX ($|\eta| < 2.0$)
- COT ($|\eta| < 1.0$)

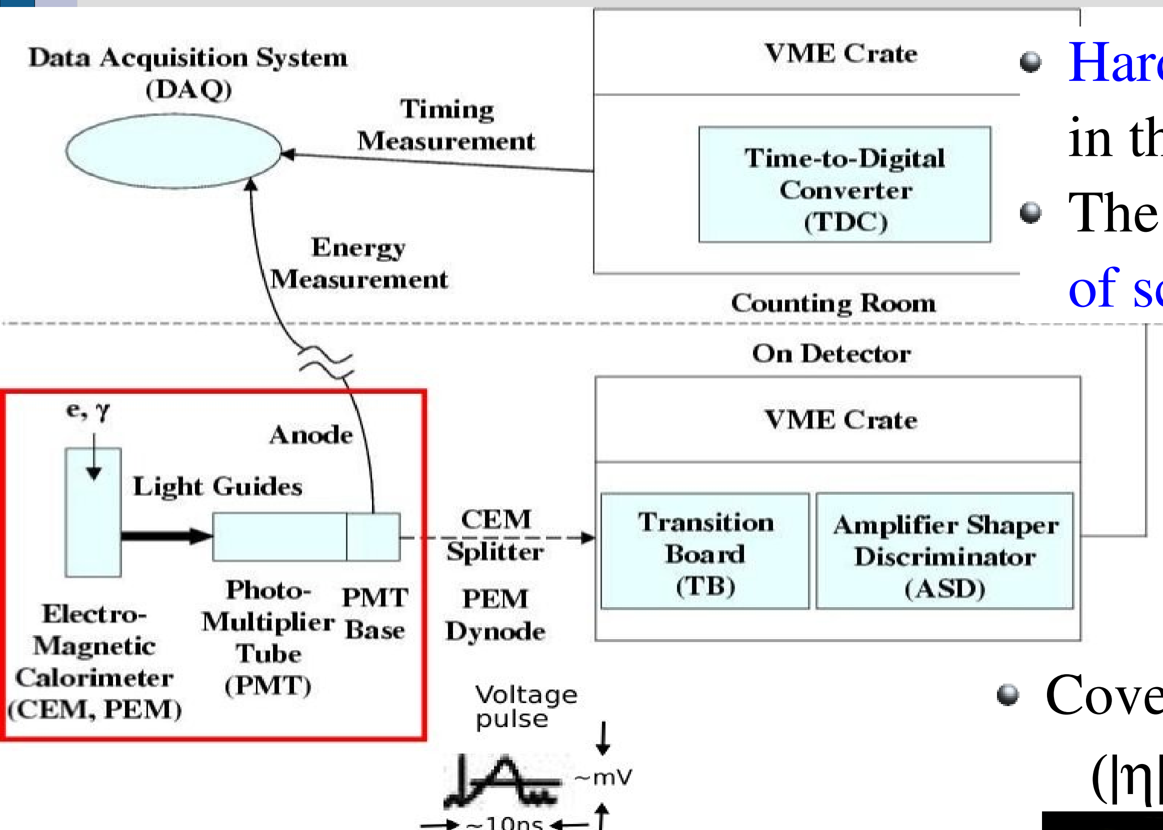
Calorimetry:

- Central: CEM, CHA ($|\eta| < 1.0$)
- Endcap: PEM ($1.0 < |\eta| < 3.6$)

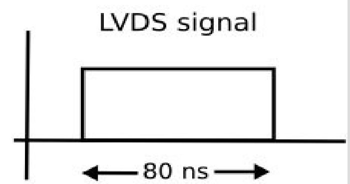


NEW New at CDF: Timing in the EM calorimeter - EMTiming

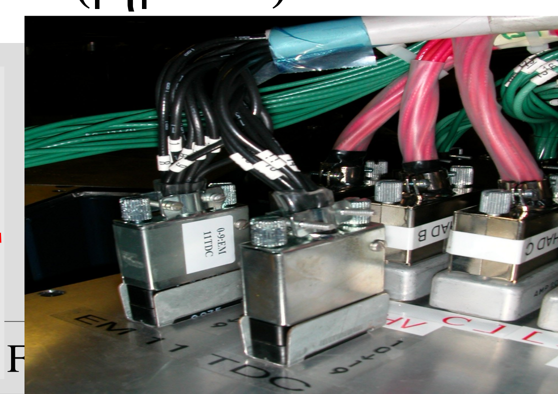
M. Goncharov, D. Toback, P. Wagner et.al., Nucl. Instr. Meth. A565, 543 (2006)



- Hardware similar to Timing system in the Hadronic Calorimeter (HAD)
- The installation was finished ahead of schedule in Fall 2004



- Covers most of the EM calorimeter ($|\eta| < 2.1$)



- 100 % efficient for photons with >3.5 GeV (CEM)
- Only 1 channel failure in 40000 PMT months!

Thanks go to...

Max Goncharov, Slava Krutelyov, Eunsin Lee, Dave Toback

The success of this analysis at any stage depended very much on each of them...

... and many others at CDF!!

EMTiming Resolution

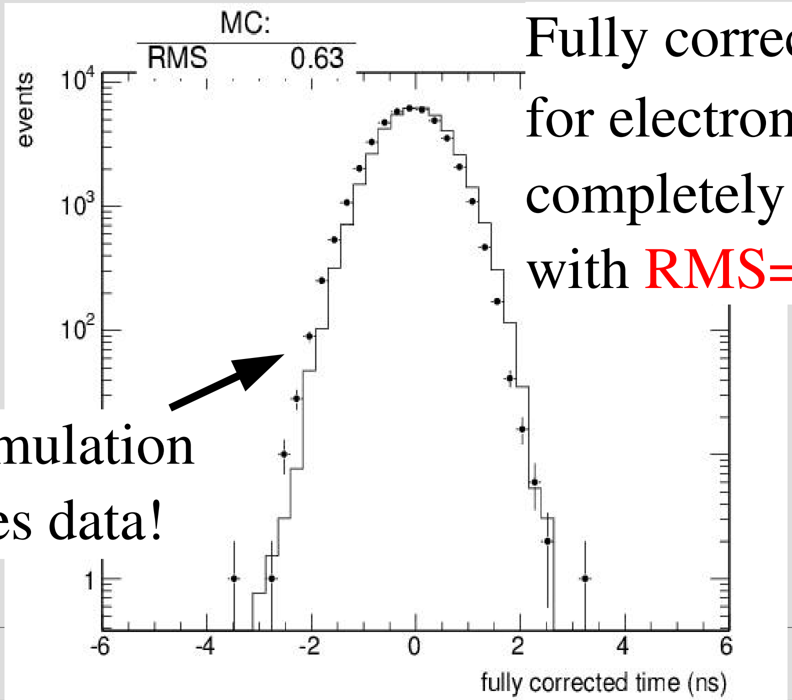
Apply calibrations to the EMTiming TDC time to correct for:

- Its dependence on the energy deposited
- Its dependence on where the photon showers into the tower (PMT asymmetry)

Then apply offline event-by-event “corrections” to take into account:

- Collision time: measured by vertex reconstruction in space and time NEW
- Time of flight due to variation of the collision position

⇒

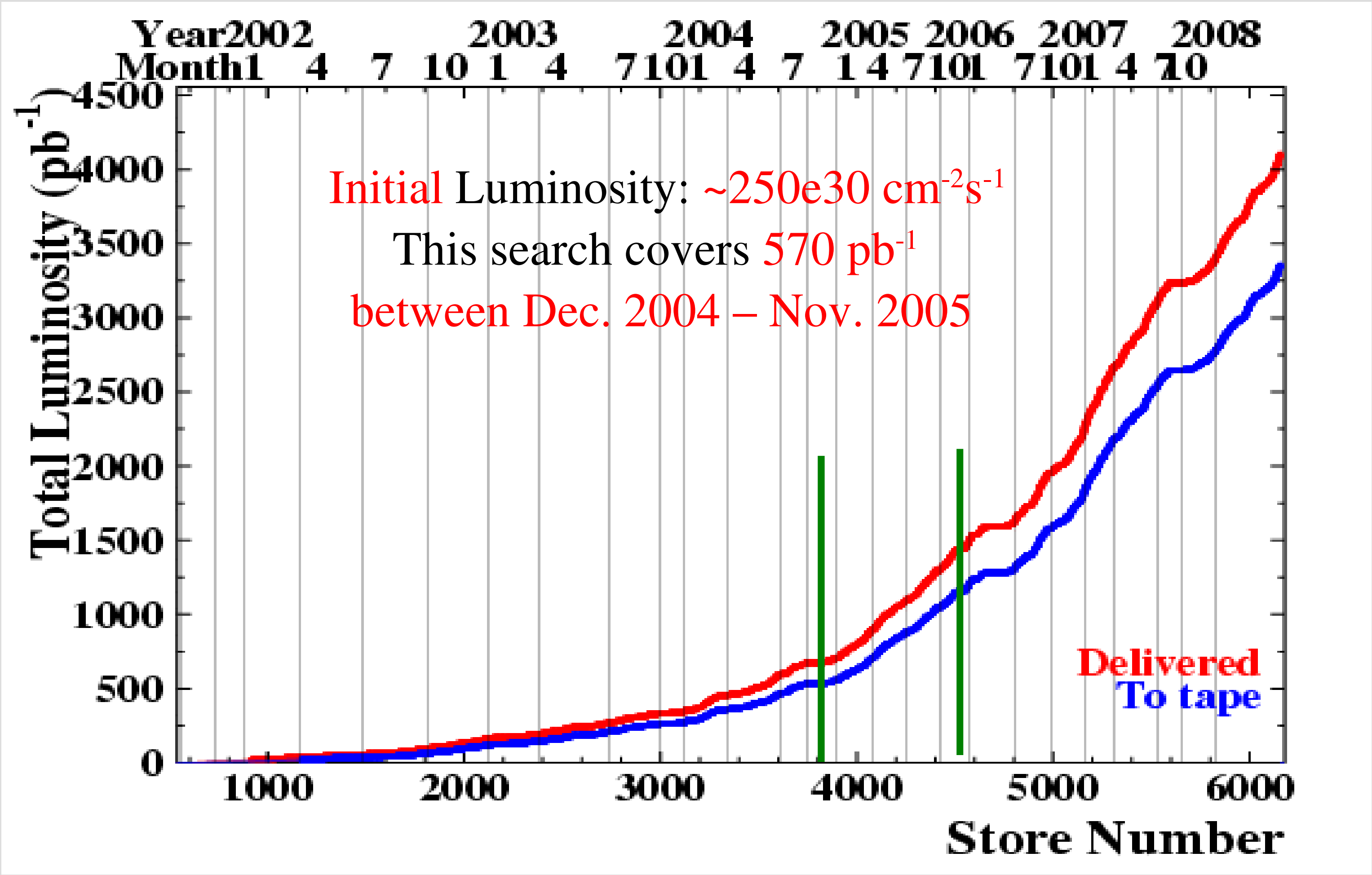


Fully corrected time distribution for electrons from $W \to e\nu$ completely Gaussian with RMS=0.64ns

MC simulation matches data!

The Analysis

Data: CDF II Detector Performance



Total data recorded at CDF at the time: ~2 fb^{-1}

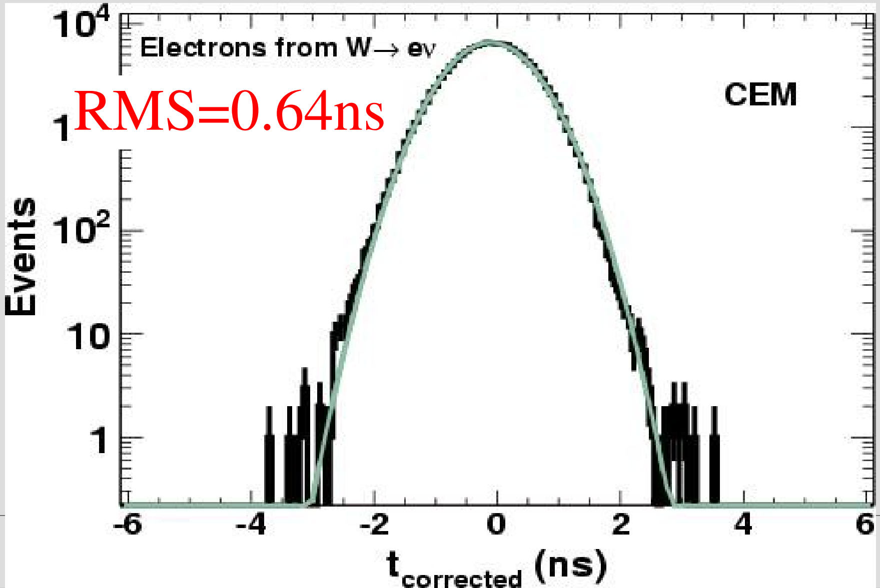
Backgrounds

(1) Collision: Standard Model photon candidates

➔ Right vertex

At high beam luminosity there may be multiple interactions for each bunch crossing ⇒ there is more than one event vertex reconstructed with a different position in space and time

If we selected the vertex that produced the photon then its corrected arrival time distribution will look like this:

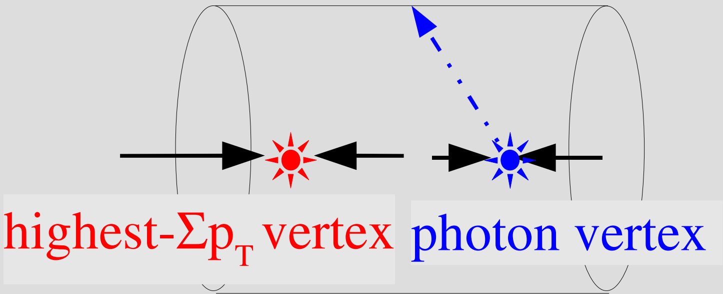


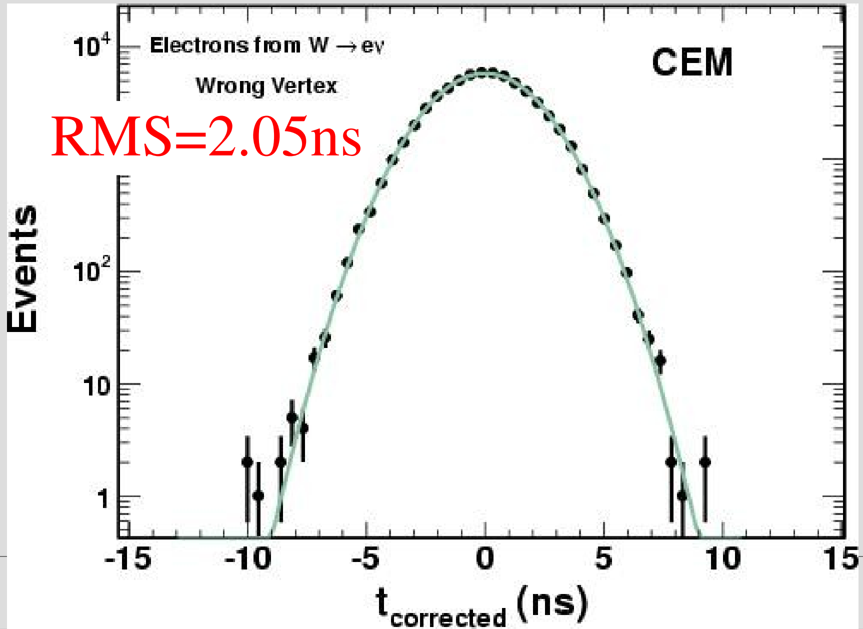
Backgrounds

(1) Collision: Standard Model photon candidates

- Right vertex
- Wrong vertex

... and if not, then the corrected photon arrival time distribution will look wider:

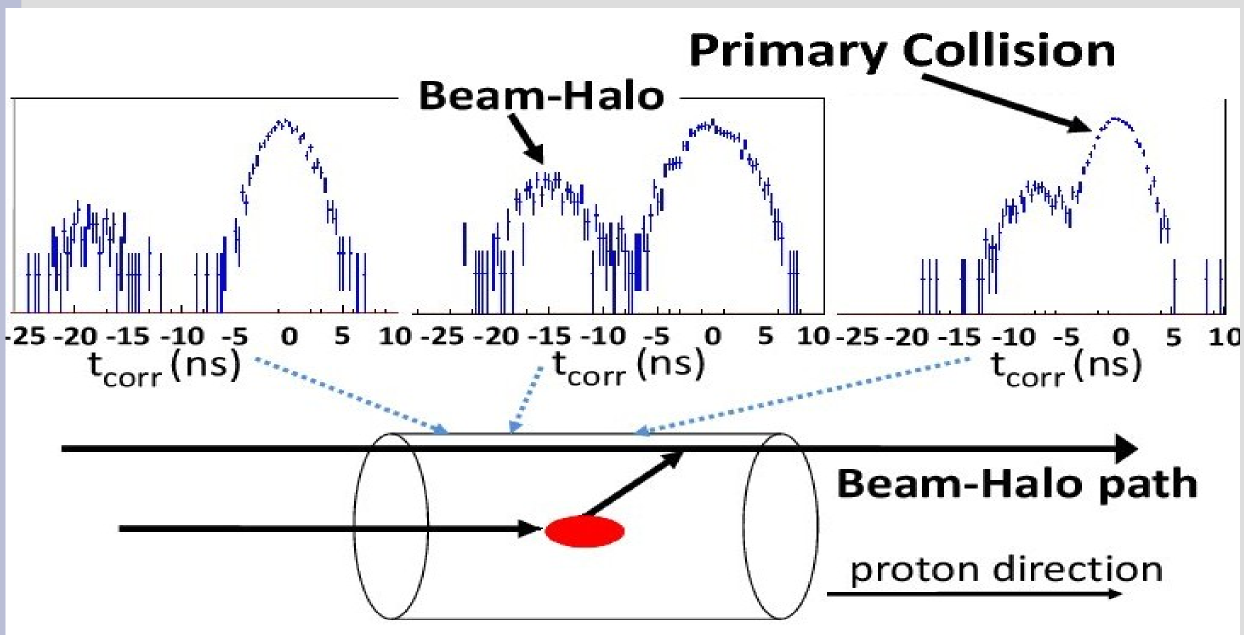


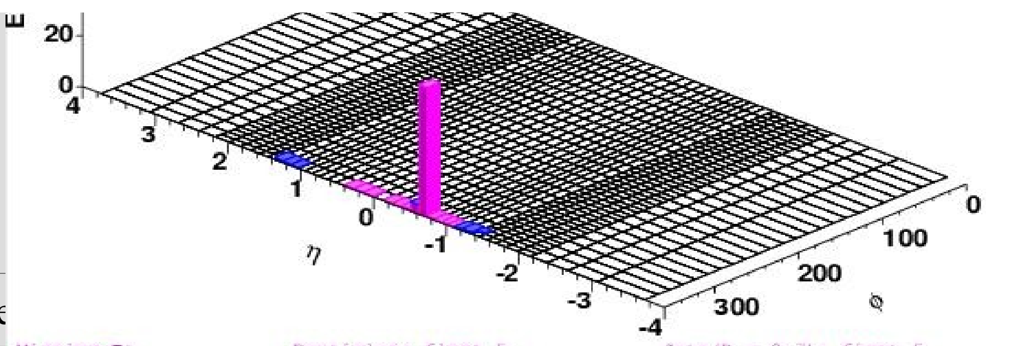


Backgrounds

(2) Non-collision photon candidates

- Cosmics: Bremsstrahlung in the calorimeter from a cosmic ray shower
- Beam Halo: is produced by proton-bunch interactions with the beam pipe that scatter off muons that can traverse the calorimeter

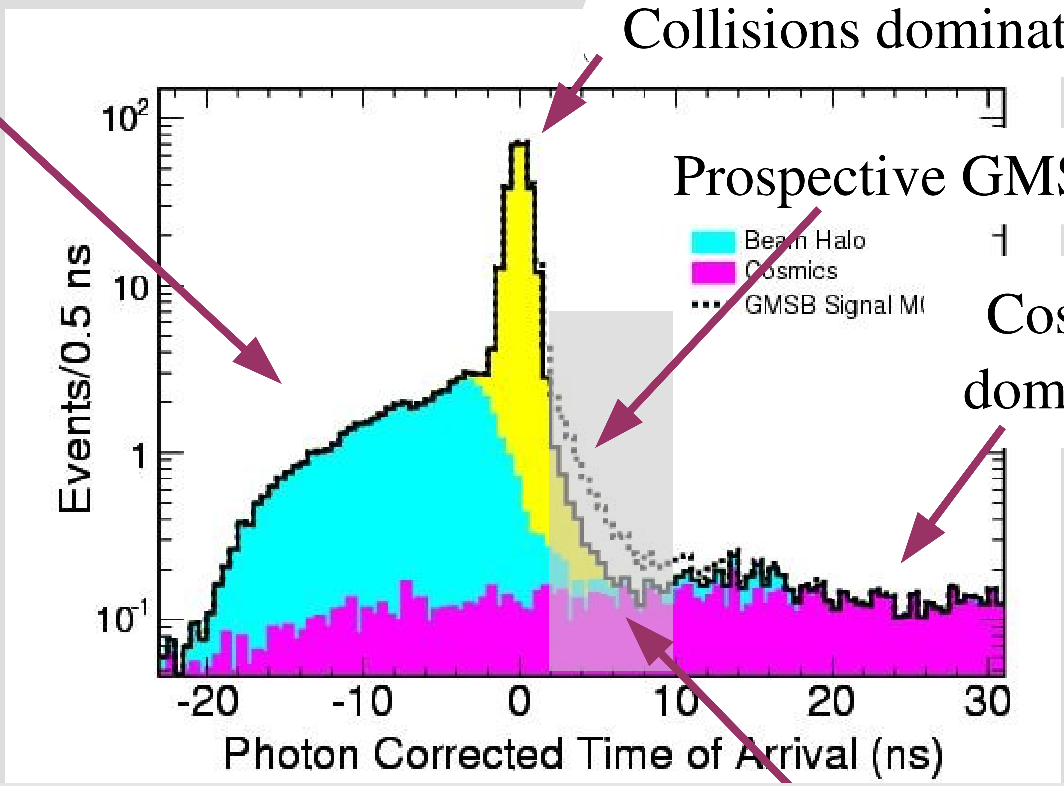




1) These photons mostly have negative arrival times for geometrical reasons if the beam halo muon came from the primary collision bunch
2) They mostly occupy multiple towers in the same wedge ⇒ can separate them from cosmics

Background Prediction

- Take the collision time shape from a W→eν sample, the non-collision shape from a data sample without tracks
- Fit each background shape to a time window in the $\gamma+\not{E}_T$+jet data where the respective background dominates
- Vary the normalization of each shape:



- Predict the number of events in the blinded signal region

Event Preselection

- Not GMSB specific!
- Require a central high-E_T photon, $\not\!\!E_T$ and at least one high-E_T jet
- Trigger fully efficient at photon $\not\!\!E_T$ > 30 GeV and $\not\!\!E_T$ > 30 GeV 39%
- Good vertex in space and time with >4 tracks that have a total p_T of >15 GeV to reduce non-collision backgrounds 31%
- Require a jet with E_T > 30 GeV to reduce non-collision backgrounds 24%
- No potential muon within 30^o to reduce cosmics 23%

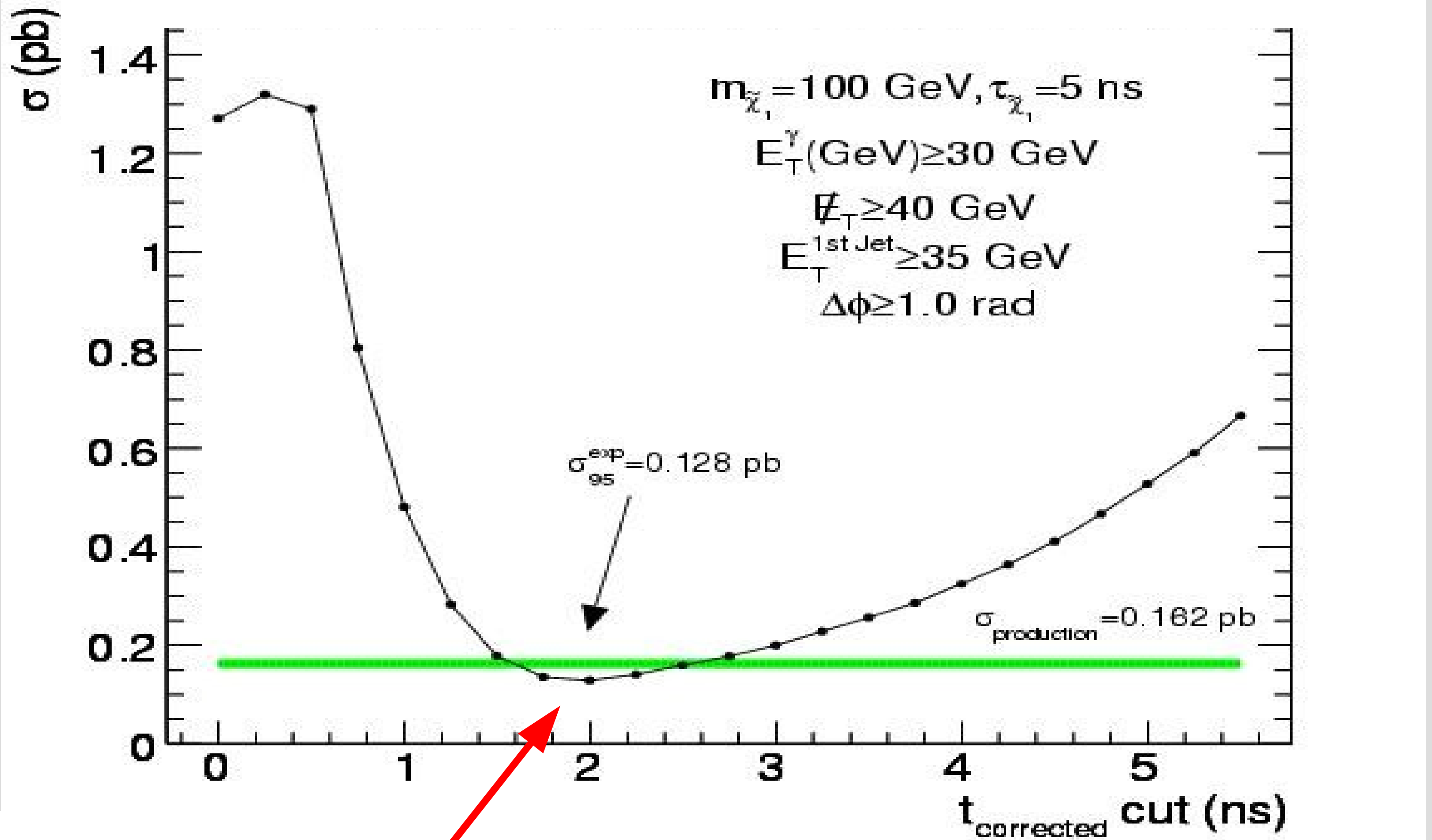
Efficiencies for a signal with $m_\chi = 100$ GeV and $\tau_\chi = 5$ ns

Optimization

- Idea: Find a fixed set of *a-priori* event selection cuts before unblinding the signal region
- Method: We calculate the 95% C.L. expected cross section limit, taking into account the expected number of background events, luminosity, GMSB acceptance and their errors
- The result is a function of the event selection cuts: Photon E_T, jet E_T, $\not{E}_T$, $\Delta\phi(\not{E}_T$,jet) and time window
- Pick the lowest limit
- Map it out as a function of the $\tilde{\chi}_1^0$ mass and lifetime

Comparison of Signal and Bkg

m_χ = 100 GeV and τ_χ = 5 ns
Prod. cross section: 0.162pb



Choose optimal cut at 2ns

Optimization Result

Dominant systematics:

- mean and RMS of the collision time distribution (7%)
- ID efficiency (5%)
- stat. uncertainty on the fit of the time shapes (determined by the fit)

Final cuts:

- Photon E_T: 30 GeV
- $\not{E}_T$: 40 GeV
- Jet E_T: 35 GeV
- $\Delta\phi(\not{E}_T,\text{jet})$: 1.0 rad
- t_{min}: 2.0 ns

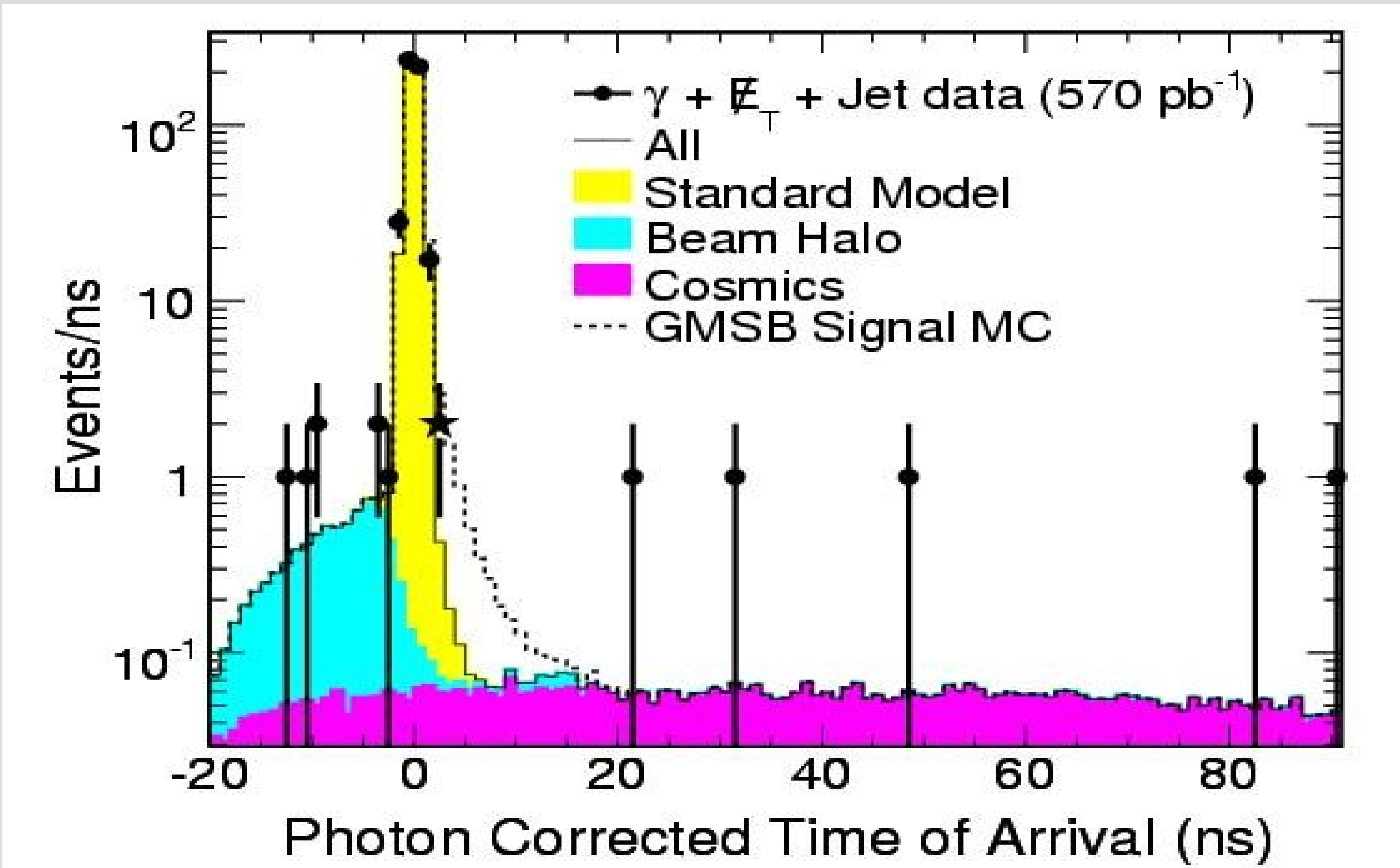
$\Rightarrow$ open the box with these cuts

Expected Background: 1.3 ± 0.7

(SM 0.7 ± 0.6; Cosmics 0.5 ± 0.3; BH 0.1 ± 0.1)

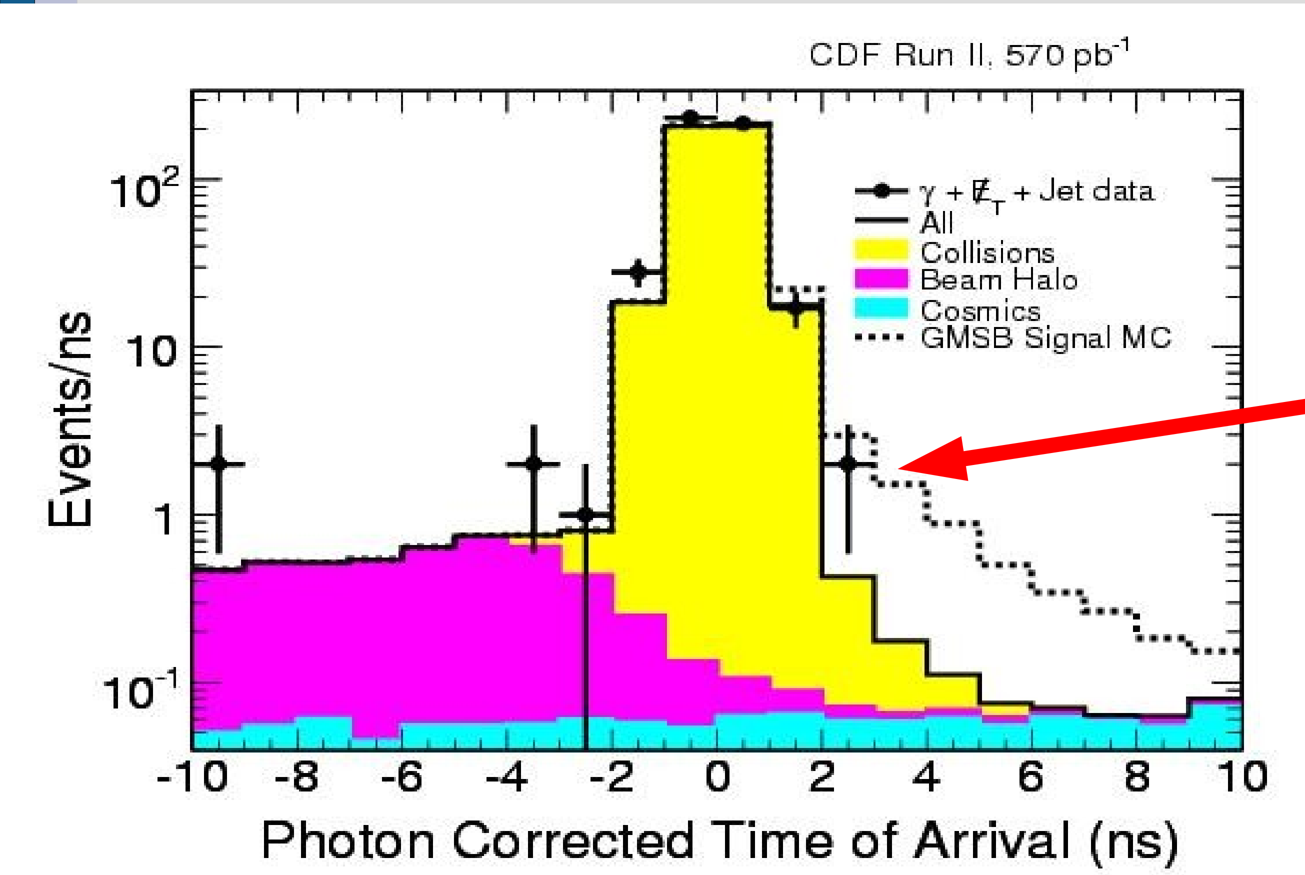
Expected $\tilde{\chi}_1^0$ mass limit: 108 GeV at 5 ns (5.5 signal events)

Unblinding the Signal Region – Overview



The predicted shapes for the total time window

The Data

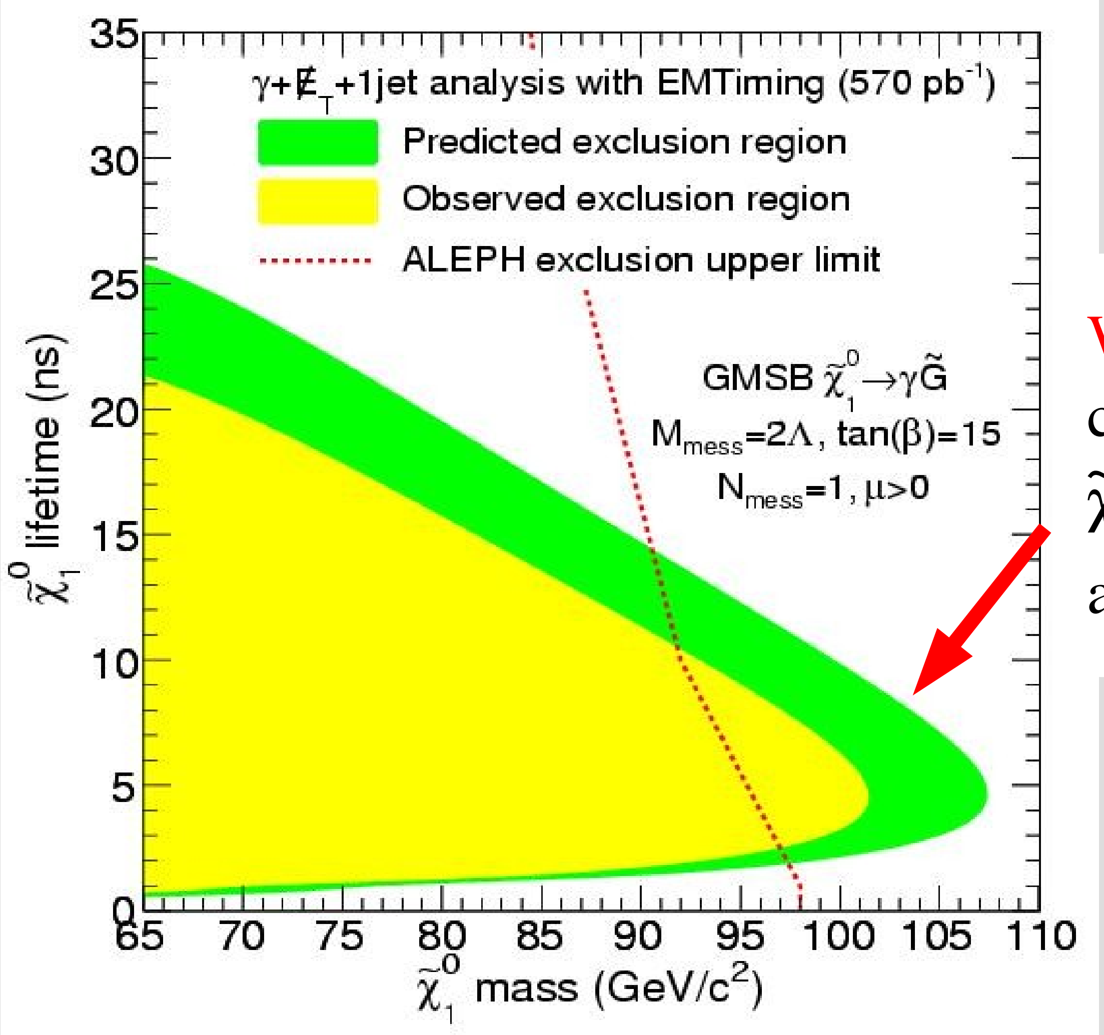


We observe 2 events in the signal region (predicted 1.3±0.7)

Event 1: looks like a QCD event where both $\not{E}_T$ and photon time are mis-measured by a combined deviation of 5.6σ

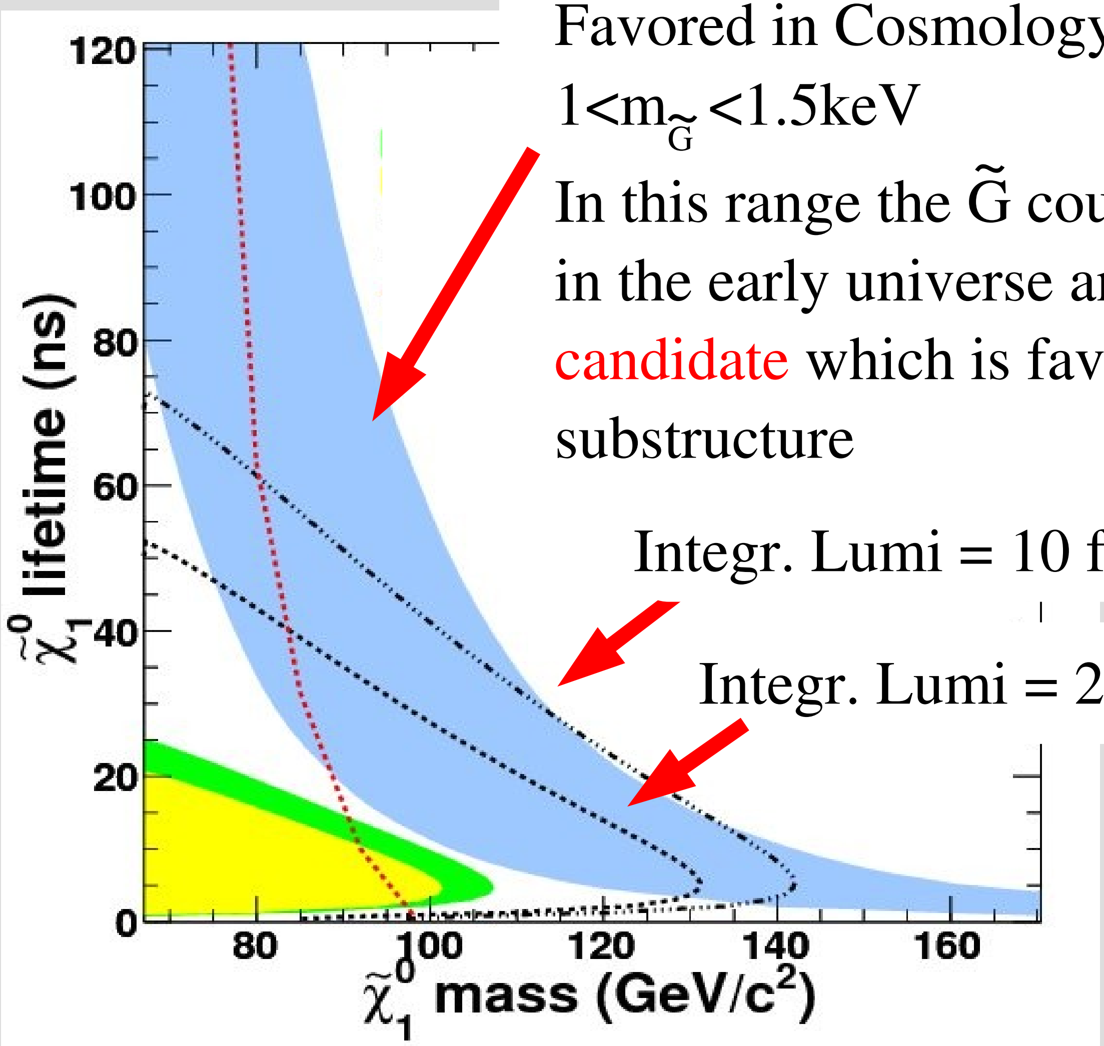
Event 2: likely a W→eν+jet event where the electron brem'd early in the tracking chambers and the wrong vertex has been selected

Exclusion Region



World best observed cross section limit on the $\tilde{\chi}_1^0$ mass of 101 GeV at a lifetime of 5ns

Prospects



Favored in Cosmology:

$1 < m_{\tilde{G}} < 1.5$keV

In this range the $\tilde{G}$ could be thermally produced in the early universe and be a warm dark matter candidate which is favored to explain galaxy substructure

Integr. Lumi = 10 fb^{-1}

Integr. Lumi = 2 fb^{-1}

There are already 3 fb^{-1} on tape...

Conclusion

This was the first search for heavy long lived particles decaying to photons at a hadron collider:

- First result using the newly installed EMTiming system (640ps resolution)
- Background predictions are entirely from data
- Requirements are chosen to be most sensitive to GMSB models important to cosmolgy
- We observe 2 events which is consistent with the background estimate of 1.3 ± 0.7
- With 570 pb^{-1} we set the world-best exclusion limits beyond the final LEP limits on GMSB models and exclude all models that produce more than 5.5 events
- Produced a PRD (D70, 114030), a NIM (A565, 543 (2006)), a PRL (FNAL PUB-07-075-E), another PRD is accepted for publication (at the 2nd PRD review)